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(54) [Title of the Invention]

PARTIAL OBJECTIVE LENS IN ILLUMINATING SYSTEM

(57) [Abstract]

[Problem] To extend the application of a chief ray in an image

plane of a partial objective lens over a wide range.

[Means for Resolution] In an irradiating device of a microlithographic projection exposure apparatus, the partial objective lens 1 having an optical axis OA for irradiating an image field is disposed between an aperture plane APE and an image plane IM. The partial objective lens 1 includes: a first lens group 3 and a lens L15 having a first aspheric surface S111. A second lens group 5 includes at least one first lens L15 having negative refractive power and at least one second lens L14 having positive refractive power. The maximum field height Y_{im}^{max} within an image field is at least 40 mm, and on the other hand, the image-side numerical aperture is at least 0.15. The chief rays within the image field have field heights Y_{im} and chief ray angles PF.

[Claims]

[Claim 1] A partial objective lens 1, 301, 501, having an optical axis OA for illuminating an image field in an illuminating device of a microlithographic projection exposure apparatus,
wherein the partial objective lens 1, 301, 501 is disposed between an aperture plane APE and an image plane IM, ray bundles, each of which has a chief ray, radiate from the aperture plane APE, the intersection points of the chief rays with the optical axis OA are situated apart by at maximum 10% of the diameter of the aperture plane (APE),

the partial object lens 1, 301, 501 includes: a first lens group 3, 303, 503; and a second lens group 5, 305, 505,

within the first lens group 3, 303, 503, an outermost chief ray HS, which passes through the aperture plane APE at a maximum angle to the optical axis OA, has numerically a smaller radiation height at the surfaces of the lenses than a marginal ray (RS) which bounds the ray bundle whose chief ray travels along the optical axis OA,

on the other hand, within the second lens group 5, 305, 505, the outermost chief ray HS has numerically greater ray heights at the lens surfaces than the marginal ray RS,

the second lens group 5, 305, 505 has a lens L15, L39, L510 with a first aspheric lens surface S111, S320, S523, the second lens group 5, 305, 505 has at least a first lens L15,

L39, L511 with negative refractive power and at least a second lens L14, L38, L58 with positive refractive power,

the maximum field height Y_{im}^{max} within an image field is at least 40 mm, and the image-side numerical aperture is at least 0.15, and

the chief rays within the image field have field heights Y_{im} and chief ray angles PF made between the surface normals of the image plane IM and the respective chief rays, the distribution of the chief ray angles PF over the field heights Y_{im} being given by a pupil function $PF(Y_{im})$ which consists of a linear part and a non-linear part

$$PF(Y_{im}) = c_1 \cdot Y_{im} + PF_{NL}(Y_{im})$$

wherein c_1 corresponds to the slope of the pupil function at the field height $Y_{im} = 0$ mm, and the non-linear part is at least +15 mrd for the maximum positive field height Y_{im}^{max}.

[Claim 2] The partial objective lens according to claim 1, wherein the first lens L15, L39, L511 has a lens surface S112, S321, S525 concave toward the image plane IM.

[Claim 3] The partial objective lens according to claim 2, wherein the lens has a radius of curvature and a lens diameter of the concave lens surface S112, S321, S525, and the ratio of the radius of curvature to the lens diameter is under 1.0, preferably under 0.8.

[Claim 4] The partial objective lens according to one of claims 2 to 3, wherein the first lens L39, L511 is a meniscus

lens.

[Claim 5] The partial objective lens according to one of claims 2 to 4, wherein with respect to the direction of light irradiation, no further lens with optical refractive power is arranged after the first lens L15, L39, L511.

[Claim 6] The partial objective lens according to claim 5, wherein the lens has a distance of the vertex of the concave lens surface S112, S321, S525 from the image plane IM and a numerical value of radius of curvature of the concave lens surface S112, S321, S525, and the ratio of the distance to the numerical value has a value between 0.7 and 1.3.

[Claim 7] The partial objective lens according to claim 5 or claim 6, wherein the lens has a first distance of the vertex of the concave lens surface S112, S321, S525 from the image plane IM, a second distance given by half the radius of curvature of the concave lens surface S112, S321, S525 and a difference between the first distance and the second distance, and the ratio of the different to the second distance is greater than 0.3.

[Claim 8] The partial objective lens according to one of claims 1 to 7, wherein the image plane IM and the lens surfaces of the second lens group 5, 305, 505 partially reflect incident rays, and the outermost chief ray HS, after reflection at the image plane IM and reflection at a lens surface of the second lens group 5, 305, 505, has a radiation height in the image

plane IM which is at least 30% of the maximum field height Y_{im}^{max}.

[Claim 9] The partial objective lens according to one of claims 1 to 8, wherein the first aspheric lens surface S111, S320, S523 has a vertical height deviation to an envelope sphere which intersects the aspheric lens surface S111, S320, S523 in the vertex and at the edge of the illuminated region of the aspheric lens surface S111, S320, S523 and the numerical value of the maximum deviation of the vertical height is at least 0.2 mm, preferably at least 0.4 mm.

[Claim 10] The partial objective lens according to one of claims 1 to 9, wherein the lens has an image-side working distance, which is at least 30 mm, preferably at least 40 mm.

[Claim 11] The partial objective lens according to one of claims 1 to 10, wherein the non-linear part $PF_{NL}(Y_{im})$ of the positive maximum field height Y_{im}^{max} is at least +25 mrad.

[Claim 12] The partial objective lens according to one of claims 1 to 11, wherein at least one further lens L58 of the second lens group 505 has a second aspheric surface S518.

[Claim 13] The partial objective lens according to claim 12, wherein the second aspheric lens surface S518 has a vertical height deviation to an envelope sphere which intersects the second aspheric lens surface S518 in the vertex and at the edge of the illuminated region of the second aspheric lens surface S518, and the numerical value of the maximum deviation of the vertical height is at least 0.2 mm, preferably at least 0.4

mm.

[Claim 14] The partial objective lens according to one of claims 1 to 13, wherein for the maximum field height Y_{im}^{max}, the ratio of the non-linear part PF_{NL} (Y_{im}^{max}) to the linear part $c_1 \cdot Y_{im}^{max}$ is in the range from −0.5 to −0.2.

[Claim 15] The partial objective lens according to one of claims 1 to 14, wherein all ray bundles, which completely fill the image-side numerical aperture, produce each one spot image having a diameter in the image plane IM within the image field, and the maximum diameter of all spot images is 2% of the maximum field height Y_{im}^{max}.

[Claim 16] The partial objective lens according to one of claims 1 to 15, wherein the second lens L14, L38, L58 having positive refractive power is a meniscus lens.

[Claim 17] The partial objective lens according to one of claims 1 to 16, wherein the second lens group 5, 305, 505 includes three to five lenses having the final focal length.

[Claim 18] The partial objective lens according to one of claims 1 to 17, wherein the second lens group 5, 505 has a biconvex lens L13, L510.

[Claim 19] A REMA objective lens 309, 509 for imaging an object field onto an image field, comprising: a first partial objective lens 311, 511 disposed between an object plane OBJ and an aperture plane APE; and a second partial objective lens 301, 501 as claimed in at least one of the claims, which is

disposed between the aperture plane APE and the image plane IM,

wherein the first partial objective lens 311, 511 and the second partial objective lens 301, 501 have a common optical axis OA,

chief rays starting from the object field intersect the optical axis OA in the region of the aperture plane APE, and

the REMA-objective lens 309, 509 images the object field with a magnification of three to eight times onto the image field in the image plane IM.

[Claim 20] The REMA objective lens according to claim 19, wherein each ray bundle which starts from a point within the object field and completely fills the image-side numerical aperture in the image plane IM produces a spot image within the irradiation surface, and the maximum diameter of the spot images is 2% of the maximum field height Y_{im}^{max}.

[Claim 21] The REMA objective lens according to claim 19 or claim 20, wherein the chief rays start telecentrically from the object plane DBJ.

[Claim 22] The REMA objective lens according to one of claims 19 to 21, wherein a chief ray and an energy-weighted average ray with an angular deviation between the energy-weighted average ray and the chief ray are given for each field height Y_{im} in the image plane IM, and the maximum angular deviation for all field heights is smaller than 2 mrad, preferably 1 mrad.

[Claim 23] A microlithographic projection exposure apparatus 715, 915, comprising: an illuminating device with the partial objective lens 701, 901 as claimed in at least one of the claims; and a projection objective lens 741, 941, which images an object field in an object plane onto an image field in an image plane,

wherein the projection objectie lens 741, 941 has an object-side pupil function which results as the distribution of objective lens chief ray angles over object heights within the object field of the projection objective lens 741, 941,

the partial objective lens 701, 901 and the projection objective lens 741, 941 have a common optical axis OA,

the image plane IM of the partial objective lens 701, 901 and the object field of the projection objective lens 741, 941 are situated in a common plane, and

the deviation between the pupil function of the partial objective lens and the object-side objective lens pupil function of the objective lens 701, 901 is under 2 mrad, preferably 1 mrad for all field heights within the image field of the partial objective lens.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belong]

This invention relates to a partial objective lens in an illumination system of an illuminating device of a

microlithographic projection exposure apparatus, a REMA objective lens including this type of partial objective lens, and an illuminating device of a microlithographic projection exposure apparatus having this type of objective lens.

[0002]

[Prior Art]

The partial objective lens includes a first lens group and a second lens group disposed between an aperture plane and an image plane, and an image filed to be illuminated is situated in the image plane. The components are arranged centered about an optical axis. The pencils of rays, respectively having one chief ray, enter the partial objective through the aperture plane, and the chief rays intersect the optical axis in the region of the aperture plane. The axial distance of the intersection points of the chief rays with the optical axis is here at maximum 10% of the diameter of the aperture diaphragm. The axial distribution of the intersection points depend upon the aberrations of pupil imaging introduced by the parts of the optical system arranged before the partial objective lens. Pupil imaging denotes here imaging between the pupil planes. The outermost chief ray, which passes through the aperture plane at the maximum angle to the optical axis, enters the image plane in the periphery of the image field in the image plane. The ray bundle whose chief ray travels along the optical axis defines a central ray bundle. The first lens group then

includes lenses in which the outermost chief ray has smaller ray heights at the lens surfaces than the edge beam of the central ray bundle. The second lens group includes lenses in which the outermost chief ray has greater ray height at the lens surfaces than the marginal ray of the central ray bundle. A lens of the second lens group has an aspheric lens surface here.

[0003]

A microlithographic projection exposure apparatus including a partial objective lens of the category concerned between a tandem condenser and a structure-carrying mask part in the interior of an illuminating device is publicly known from DD292 727. A projection objective lens follows the structure-carrying mask in the optical path, and the lens images the structure-carrying mask onto a photosensitive substrate with limited diffraction. The first lens group of the partial objective image corresponds to the collimator in DD 292 727, and the second lens group corresponds to a field lens consisting of only one lens. The field lens has an aspheric correction surface here, in order to affect the angular distribution of the chief rays in the image plane of the partial objective lens such that the image plane of the projection objective lens is illuminated nearly telecentrically. The aberrations of pupil imaging between the aperture plane of the partial objective lens and the aperture

plane of the projection objective lens are reduced by the aspheric correcting surface. The disadvantage of constitution of DD292 727 is that since the field lens consists of only a single lens with positive refractive power, the possibilities of correction of pupil imaging is limited. Moreover, the embodiment has only an image-side numerical aperture of 0.04 and a maximum field height of 71.75 mm.

[0004]

The so-called REMA objective lens is publicly known to the applicant of this case from DE195 48 805 A1 (U.S. Patent No. 5,982,558) and DE196 53 983 A1 (U.S. Patent No. 09/125621). The REMA objective lens is fitted directly before the structure-carrying mask, the so-called reticle, in the microlithographic projection exposure apparatus. This lens images the masking device, the so-called REMA (reticle masking) blade on the reticle with small blur at the peripheral part. The REMA blade usually includes an adjustable mechanical edge, thereby altering the size of the object field of the following REMA objective lens. While a REMA objective lens with purely spherical lenses is shown in the embodiment of DE19548 805 A1, the use of aspheric lenses for reducing the number of lenses within a REMA objective lens is proposed in DE196 53 983 A1. In this case, the field lens portion of the REMA objective lens matches the angular distribution of the chief rays of the REM objective lens to the angular distribution of the chief rays

of a following projection objective lens in order to attain a continuous course of rays between the REMA objective lens and the projection objective lens.

[0005]

EPO 811 865 A1 discloses a partial objective lens, which is disposed between an aperture plane and an image plane. In this case, not a reticle, but a masking device, is arranged in the image plane of the partial objective lens, and is imaged onto the reticle by a following objective lens. Therefore, the partial objective lens has no direct influence on the distribution of the chief ray angle at the interface between the illuminating device and a following projection objective lens.

[0006]

Microstructured components with structure sizes below 0.2 μm can be produced with a modern projection objective lens. In order to attain these high resolutions, the projection objective lenses are operated at wavelengths of 248 nm, in particular 193 nm or even 157 nm, and have image-side numerical apertures of greater than 0.65. At the same time, the image field diameter is partly greater than 20 mm. Therefore, the requirements on the optimum optical design for such a projection objective lens are considerable. Besides the field imaging of the reticle onto the photosensitive substrate, the so-called wafer, the pupil imaging is also to be corrected.

Thus the forward objective lens portion, arranged between the object plane and the aperture plane, of a projection objective lens influences the imaging of the entrance pupil onto the aperture plate, while the rearward objective lens portion, arranged between the aperture plane and the image plane, influences the imaging of the aperture plane onto the exit pupil. The aberrations of pupil imaging of the projection objective lens then become apparent in the distribution of the chief ray angles in the object plane of the projection objective lens.

[0007]

[Problems that the Invention is to Solve]

It is an object of the invention to provide a partial objective lens of the above type, which permits influencing the distribution of the chief ray angles in the image plane of the partial objective lens over wide ranges. In particular, aberrations of pupil imaging that are performed by the forward objective lens portion of a following projection objective lens are to be compensated.

[0008]

[Means for Solving the Problems]

The problems are achieved by the partial objective lens described in claim 1. Special embodiments of the invention are described in dependent claims 2 to 23. The claims 1 to 18 relate to the partial objective lens according to the invention, and the claims 19 to 22 relate to a REMA objective

lens to which the partial objective lens is fitted. An embodiment in which the partial objective lens of the invention is used in a microlithographic projection exposure apparatus is described in claim 23.

[0009]

The distribution of chief ray angles PF in the image plane of the partial objective lens over the field height Y_{im}, that is, the so-called pupil function is represented as the series expansion formula having odd powers. This polynomials is as follows.

[Expression 1]

$$PF(Y_{im}) = \sum_n c_n \cdot Y_{im}{}^n \quad (n=1,3,5,7,9\ldots) \qquad (1)$$

[0010]

The chef ray angles PF, which are determined between the surface normals of the image plane and the respective chef rays, are defined to be negative in the clockwise direction. Ongrounds of symmetry, the pupil function for an optical system symmetrical centered around the optical axis has no part with even powers. In the case where no aberrations of pupil imaging is in the image plane of the partial objective lens according to the invention, the same axial position of the exit pupil for each field height Y_{im}, that is, a homocentric exit pupil is caused. In the case of homocentric exit pupils, all chief rays interest the optical axis at one point, so there exists

exclusively a linear connection between the field height Y_{im} and the tangent of the angle for each chief ray. In the following cases, with very small chief ray angles, the tangent of the chief ray angle can be directly approximated by the angle. The pupil function for a homocentric pupil has only a linear part $c_1 \cdot Y_{im}$, where the coefficient c1 corresponds to the slope of the pupil function at Y_{im} = 0 mm. However, due to the aberrations of pupil imaging, a different axial position of the exit pupil is caused for each field height. The field-dependent position of the exit pupil is described by the non-linear part.

[Expression 2]

$$PF_{NL}(Y_{im}) = \sum_{n} c_n \cdot Y_{im}{}^{n} \quad (n=1,3,5,7,9\ldots) \qquad (2)$$

[0011]

The parts of higher order correspond here to the spherical angular aberration of the pupil imaging. Accordingly, the spherical aberration is expressed as angular aberration. The optical system having positive refractive power is usually spherically under-corrected without special correction means, so that the non-linear part PF_{NL} of the pupil function is negative for a positive field height. In contrast to this, the pupil function of the partial objective lens according to the invention has a non-linear part PF_{NL} which is clearly positive for positive field heights. The non-linear

part PF_{NL} (Y_{im}^{max}) to the chief ray angle is at least +15 mrad for the maximum positive field height. Thus, the partial objective lens introduces a strong over-correction of the spherical aberration of pupil imaging. This is particularly advantageous because the following projection objective lens can thereby be spherically under-corrected, and correction means in the projection objective lens can thereby be saved. It is always more favorable to install these correction means in the illuminating system. The reason is that the quality requirements on optical elements in a projection objective lens are clearly higher than those on optical elements in the illuminating system. The partial objective lens according to the invention attains this over-correction in an image field which has a diameter of at least 80 mm, and whose image-side numerical aperture is at least 0.15. The image-side numerical aperture denotes here the numerical aperture in the image plane, which is possible due to the maximum aperture diaphragm diameter of the partial objective lens. The photoconductivity value, which is defined in this case as the product of the image field diameter and the image-side numerical aperture, is at least 12 mm. The over-correction of the spherical aberration of pupil imaging can be attained when the second lens group of the partial objective according to the invention consists of at least two lenses, a first lens having a negative refractive power and a second lens having a positive refractive

power.

[0012]

It is advantageous for the correction of spherical aberration of pupil imaging when the first lens of negative refractive power has a lens surface concave to the image plane, so that the radius of curvature of this surface is positive.

[0013]

It is favorable that the ratio of radius of curvature to lens diameter of the concave lens surface is under 1.0, preferably under 0.8. The lower limit of this ratio is the value 0.5, which results for a hemisphere. Due to the strongly curved concave lens surface, large angles of incidence of the chief rays of the picture elements remote from the axis result on this lens surface, and a large contribution results to the over-correction of the spherical aberration of pupil imaging.

[0014]

Preferably the first lens having negative refractive power is designed as a meniscus. In the case of the meniscus lens, the signs of the vertex radii of the front and back surfaces are positive.

[0015]

In that case, the first lens having negative refractive power is to be arranged as close as possible to the image plane. It is advantageous, if up to plane-parallel plate such as a filter or a projection plate, which can also be provide with

correction surfaces having random surface profiles, no further optical elements are arranged in the optical path between the first lens and the image plane.

[0016]

It is advantageous for the correction of field imaging, that is, the imaging of the pencils of rays in the image plane, when the concave lens surface of the first lens is a surface nearly concentric with the image plane. In this case, the rays of the central ray bundle pencil with small angles of incidence enter the concave lens surface. This is achieved when the ratio of the distance of the image plane from the vertex of the concave lens surface to the numerical value of the radius of curvature of the concave lens surface has a value between 0.7 and 1.3. While the rays of the central ray bundle pass nearly unrefracted through the lens surface, which is nearly concentric with the image plane, large angles of incidence result for the ray pencils of the picture elements remote from the axis. Accordingly, the surface can be used ideally for the correction of the field-dependent image aberrations, while the central ray bundle remains nearly uninfluenced.

[0017]

In the case where no further lenses with optical refractive power are situated between the first lens having a concave lens surface to the image plane and the image plane, it is advantageous if half the radius of curvature of the

concave lens surface is clearly greater or smaller than the distance of the vertex of the concave lens surface from the image plane. Generally the requirement on the radius of curvature of the concave lens surface is satisfied when the reticle is situated in the image plane, which reflects the incident light rays back into the partial objective lens. Since each plane itself of the optical systems has a residual reflection with an antireflective coating, the light rays reflected from the mask are reflected back again toward the mask at the lens surface concave to the image plane. With a nearly telecentric illumination of the mask, interfering reflection is caused when the image plane is situated at the distance of the focal length of the concave lens surface acting as a mirror. The focal length of a concave mirror is defined by half the radius of curvature. The interfering reflection can be neglected when the difference between the distance of the concave lens surface from the image plane and the focal length is larger than the numerical value obtained by multiplying the focal length by the factor 0.3.

[0018]

Minimizing the interfering reflection can be also considered for the other surfaces of the second lens group. In order to prevent the occurrence of interfering reflection between the reticle and the lens surface of the second lens group, the second lens group is constructed so that the

outermost chief ray, which passes through the aperture plane at a miximum angle to the optical axis, has after a reflection at the aperture plane and a reflection at a lens surface of the second lens group, a radiation height in the image plane which is at least 30% of the maximum field height Y_{im}^{max}. With a constant refractive power of the partial objective lens, this can be attained by the variation of the curvature of the lens surface. Therefore, the intersection of the outermost chief ray with the image plane marks the 50% point of interfering reflection, so that the outermost chief ray relates to the estimation of the interfering reflection. In the case where the outermost chief ray intersects the image plane in the region of the optical axis, all further chief rays also interest the image plane in this region, and the doubly reflected pencils of rays enter it in a narrow region around the optical axis, resulting in causing clear interfering reflection.

[0019]

The first aspheric lens surface is characterized by a large vertical high deviation of at least 0.2 mm, preferably 0.4 mm, with respect to an envelope sphere. These large asphericities are a further means of correction in order to provide the overcorrection of the spherical aberration of pupil imaging. The vertical height is defined as the distance between the aspheric lens surface and the envelope sphere in the direction of the optical axis. The envelope sphere is

defined as a spherical surface which has the same vertex as the aspheric surface and which intersects the aspheric lens surface at the edge of the illuminated region of the aspheric lens surface. The illuminated region is bounded by the marginal rays of the ray bundle of the outermost chief ray.

[0020]

Further, the design of the partial objective lens is made more difficult in that the image-side working distance of the partial objective lens is to be at least 30 mm, preferably at lest 40 mm. The free working space denotes here the distance of the image plane from the vertex of the last optical surface of the partial objective lens, this distance being reduced by the maximum vertical height of the last optical surface in the case that the last optical plane is a concave surface. The free working distance makes possible free access to the image plane, in which the reticle is usually situated. The devices for positioning the reticle and changing the same have to be able to intervene in this space.

[0021]

It is possible with the partial objective lens according to the invention to overcorrect the spherical aberration of pupil imaging such that the non-linear part PF_{NL} (Y_{im}^{max}) to the chief ray angle amounts to at least +25 mrad for the maximum positive field height Y_{im}^{max}.

[0022]

This can be attained in that the second lens group has a second aspheric lens surface.

[0023]

The maximum vertical height deviation of the second aspheric lens surface from the envelope sphere is to be as much greater than 0.2 mm as possible, preferably greater than 0.4 mm.

[0024]

It is preferable that for the maximum field height Y_{im}^{max}, the ratio of the non-linear part $PF_{NL}(Y_{im}^{max})$ to the linear part $c_1 \cdot Y_{im}^{max}$ ranges from -0.5 to -2.0. In that case, the non-linear part of the maximum field height can be partially compensated by the linear part of the pupil function, so that for the positive field heights, nearly equally large maximum and minimum chief ray angles are made, and the chief rays for these field heights travel on average parallel to the optical axis. The linear part of the pupil function is adjusted by the paraxial position of the exit pupil.

[0025]

Apart from influencing the spherical aberration of pupil imaging, the partial objective lens focuses the incident ray bundle to spot images with minimum diameter in the in the image plane. For this purpose, the correction of field imaging is required. The maximum spot diameter for all spot images is advantageously 2% of the maximum field height Y_{im}^{max}. For the

measurement of the spot image and the spot diameter, the ray bundle at full opening of the aperture diaphragm is considered, so that the pencils of rays illuminate the maximum image-side numerical aperture. In that case, the spot layer is obtained by the intersection points of a ray bundle with the image plane. Primarily as the correction means, preferably the first lens group composed of a meniscus having positive refractive power and a meniscus having negative refractive power is used.

[0026]

It is favorable for the simultaneous correction of pupil imaging and field imaging when the second lens having positive refractive power is a meniscus.

[0027]

The second lens group advantageously consists of three to five lenses, in order to correct field imaging, to overcorrect the spherical aberration of pupil imaging, and to ensure a uniform illumination of the image field.

[0028]

This is in particular possible by an additional use of a biconvex lens in the second lens group.

[0029]

The partial objective lens according to the invention is advantageously fitted within a REMA objective lens, where the REMA objective lens images an object field with a magnification of three through eight times in an image field.

The REMA objective lens consists of a first partial objective lens between the object plane and the aperture plane and the partial objective lens according to the invention. The two partial objective lenses have a common optical axis. The magnification of the REMA objective lens can be adjusted through the ratio of the focal lengths of the first partial objective lens and second partial objective lens. When the pupil imaging of the first partial objective lens or of the optical components disposed before the REMA objective lens produces aberrations, the chief rays starting from the object plane do not necessarily intersect the aperture plane in one point.

[0030]

Since the REMA objective lens is to image the masking device arranged in the object plane of the REMA objective lens as sharply as possible onto the image plane in which the reticle is arranged, the spot images of the object points have the minimum diameter in the image plane. The maximum diameter of the spot image is 2% of the maximum field height Y_{im}^{max}. For the determination of the maximum spot diameter, pencils of rays are used at the maximum diaphragm aperture, which corresponds to the image-side numerical aperture.

[0031]

The entrance pupil of the REMA objective lens is advantageously situated at infinity, so that the chief rays

of the pencils of rays after the object plane travel parallel to the optical axis and thus telecentrically. By means of this measure, the imaging scale of the REMA objective lens is independent of a defocusing of the object, in this case the masking device.

[0032]

Besides the chief rays formed through pupil imaging, the energy-weighted average rays in the image plane of the REMA objective lens are also important. The energy-weighted average ray of a ray bundle represents the ray which results from an averaging over all the rays of the ray bundle under consideration, where each ray has an energetic weighing according to the illumination of the entrance pupil. For a field height Y_{im}, the direction of the corresponding energy-weighted average ray depends on the aberrations of the REMA objective lens in connection with the illumination of the entrance pupil of the REMA objective lens. The energy-weighted average rays can be defined, for example, as a complete illumination of the entrance pupil, or as an only partial illumination of the entrance pupil, the illumination being respectively nearly point-symmetrical with respect to the optical axis. The REMA objective lens is now constructed so that the maximum angular deviation between the energy-weighted average ray and the chief ray for all field heights is smaller than 2 mard, preferably smaller than 1 mrad.

This requirement, together with the requirements on the field imaging and pupil imaging, is attained with an REMA objective lens which includes eight through twelve lenses with finite focal length, the first partial objective lens having three through five lenses, and the second partial objective lens having five through seven lenses. In addition, the use of three through five aspheric lenses is advantageous.

[0033]

The partial objective lens according to the invention is advantageously used in a microlithographic projection exposure apparatus, in which a projection objective lens directly follows the partial objective lens, whereby the intersection point between the illumination system and the projection objective thus represents the image plane of the partial objective lens or the object plane of the projection objective lens, respectively. The partial objective lens and the projection objective lens are centered about a common optical axis. In order to ensure a continuous course of the pencils of rays of the illumination system and the projection objective lens, the distribution of the chief ray angles of the partial objective lens has to be matched to the distribution of the chief ray angles of the projection objective lens. The deviation between of the pupil function of the partial objective lens and the object-side objective lens pupil function is in this case advantageously under 2 mrad for all

field heights within the image field of the partial objective lens, preferably under 1 mrad. If this condition is fulfilled, the partial objective lens and the projection objective lens then form a functional unit with respect to pupil imaging. Since the aberrations of the projection objective lens can be compensated with the partial objective lens, the projection objective lens to which the partial objective lens is applied can correct clear under-correction of spherical aberration of pupil imaging. Thus, the optical correction for the projection objective lens can be remarkably relieved.

[0034]

Correspondingly, it is advantageous to use a REMA objective lens in a microlithographic projection exposure apparatus, and in that case, the REMA objective lens includes the partial objective lens according to the invention.

[0035]

The invention will now be described in detail with reference to the drawings.

[0036]

[Mode for Carrying Out the Invention]

Fig. 1 shows a lens section of a partial objective lens according to the invention. Besides the lenses, the marginal rays RS of the middle ray bundle, and also the outermost chief ray HS and the rays bounding the ray bundle of the outermost chief ray, are shown in. The partial objective lens 1 is

constructed with rotational symmetry about the optical axis. The system data are set out in Table 1. As the lens material, quartz (SiO) is used in this embodiment, it has a refractive index of 1.5603 at the working wavelength [lambda]=193.3 nm. When the transmittance is to be increased or the partial objective lens is to be used at wavelength of 157 nm or 126 nm, fluoride crystals can be also used as the lens material. With the partial objective lens 1, an image field of diameter 116.0 mm is illuminated in the image plane IM. The image-side numerical aperture is 0.18. The partial objective lens thus has a photoconductivity of 20.7 mm.

[0037]

Parallel pencils of rays enter the partial objective lens through the aperture plane APE with a diameter of 187.9 mm, and are focused to respective spot in the image plane IM. For all image points within the image field, the maximum spot diameter is 160 (1μ)m. The size of the spot diameter is defined by the correction of the field imaging and in particular by the correction of image shell and aperture aberration.

[0038]

The chief rays of the pencils of rays intersect the optical axis OA in the center of the aperture plane APE when it enters the partial objective lens 1 in Fig. 1. The angle of a chief ray in the aperture plane APE with respect to the optical axis corresponds to the field height Y_{im} of the chief

ray in the image plane IM. The maximum angle of a chief ray in the aperture plane APE is 6.3°, and corresponds to a field height Y_{im}^{max} which is 58.0 mm in the image plane IM. The focal length of the partial objective lens 1 is 487.7 mm. The pupil function PF (Y_{im}) of the partial objective lens 1 showing the angular distribution of chef rays in the image plane is shown as a solid line 27 in Fig. 2. The value of the chief rays for positive field heights is -5.3 mrad to +7.9 mrad, so that the chief rays for positive field heights travel on average nearly parallel to the optical axis. The pupil function can be developed from the polynomial series according to Equation (1), and the coefficients of which can be read from Table 2. In that case, the coefficient c_1 of first order corresponds to the slope of the pupil function at $Y_{im}=0$ and gives the paraxial position of the exit pupil or the position of the exit pupil for aberration-free. The coefficients of the third and higher orders describe the spherical aberration of pupil imaging. In Fig. 2, the linear part to the pupil function is drawn as a broken line 28 marked by squares, and the non-linear part is drawn as a broken line 29 marked by triangles.

[Table 1]

	coefficient	Polynomial part in the case of Y_{im}^{max} = 58.0 mm
C_1	-2.8566E-01mrad/mm	-16.60mrad
C_3	1.2526E-04mrad/mm^3	24.57mrad
C_5	-3.9215E-09mrad/mm^5	-2.60mrad
C_7	6.4435E-13mrad/mm^7	1.44mrad
C_9	1.5273E-16mrad/mm^9	1.15mrad

Table 2: Coefficient of Polynomial

[0039]

The polynomial parts $c_n Y_{im}^{max}$ are given in the third column of Table 2 which result for the respective order n for the maximum positive field height $Y_{im}^{max} = +58.0mm$. The largest part to the spherical aberration for pupil imaging is the part of third order, +24.6mrad, for the maximum positive field height Y_{im}^{max}. The total non-linear part is +24.6mrad. Since the non-linear part for the positive field height has a positive sign, the spherical aberration is clearly overcorrected. The ratio of the non-linear part to the linear part for the maximum field height Y_{im}^{max} is -1.48.

[0040]

The partial objective lens 1 includes a first lens group 3 and a second lens group 5. The first lens group 3 is composed of a lens L11 having positive refractive power and a lens L12 having negative refractive power. The chief ray HS of the outermost part within the lens group 3 travels between the optical axis OA and the marginal ray RS of the central ray bundle. The lenses L11 and L12 have the aspheric lens surfaces S102 and S104. The lenses L11 and the lens L12 are both meniscuses, with the convex lens surface facing toward the aperture plane APE. The first lens group 3 chiefly contributes to the correction of field imaging and thus to minimization of spot diameter of a picture element.

[0041]

In the lenses of the second lens group 5, the marginal ray RS of the central ray bundle travels between the optical axis OA and the outermost chief ray HS. There is sufficient mounting space for mounting a polarizing mirror between the first lens group 3 and the second lens group 5. The illuminating optical path, for example, can be deflected by 90° using the polarizing mirror. Alternatively, it is also possible to install a spectroscope for separating some of illuminating light for the measurement purposes. When a polarizing cubic spectroscope is used, the light rays from two optical channels can be superposed nearly loss-free. The spectroscope layer of the cubic spectroscope for 45° deflection is designed so that light polarized perpendicularly to the plane of incidence is nearly completely reflected, while light polarized parallel to the incidence surface is nearly completely transmitted. This configuration is described in more detail in the embodiment of Fig. 7.

[0042]

The second lens group 5 in Fig. 1 functions as a field lens, which mainly affects the pupil imaging. Moreover, it makes it possible to correct the distortion in field imaging, so that the luminance distribution in the image plane IM can be corrected and matched. In order to fulfill these requirements, the second lens group 5 includes the biconvex

lens L13 with positive refractive power, the meniscus L14 with positive refractive power and the lens 15 with negative refractive power. The lens surface S111 is an aspheric lens surface, the surface description of which is given in Table 1. The radius of the envelope sphere, which intersects the aspheric lens surface S111 at the vertex and at the edge of the illuminated region at 80.4 mm, is -2218.4 mm, so that the deviation of vertical height between the aspheric lens surface S111 and the envelope sphere is 0.28 mm.

[0043]

The lens L15 having the negative refractive power has a concave lens surface S112 to the image plane, the ratio of radius of curvature to lens diameter being 0.75. The lens L15 is, in the direction of light rays, the last lens with refractive power before the image plane IM, so that the concave lens surface S112 is arranged immediately before the image plane M. The free working distance between the last lens L15 and the image plane IM is 50.0 mm.

[0044]

The free working distance denotes a region along the optical axis OA in which no optical elements of the partial objective lens are situated. There is, however, the possibility of installing a plane-parallel projection plate or luminance filter after the lens L15. However, these only lead to a displacement of the image plane IM of the partial

objective lens 1.

[0045]

The partial objective lens 1 is usually disposed immediately before the reticle in an illuminating device of a microlithographic projection exposure apparatus. Since the reticle reflects back a portion of the incident light into the partial objective lens 1, the lenses of the second lens group 5 are preferably designed so that interfering reflections are minimized, whereby the light reflected at the reticle is reflected a second time at a lens surface and returns to the reticle. The minimization of the interfering reflections is attained in that the partial objective lens 1 is designed so that the outermost chief ray HS intersects the image plane IM far outside the optical axis OA after double reflection at the reticle and at a lens surface. For the lens surfaces S107 and S112, the doubly reflected chief ray HS returns to the image plane IM, while for interfering reflections between the image plane and the lens surfaces S108, S109, S110 and S111, the outermost chief ray no longer reaches the image plane at all, but strikes the frame of the partial objective lens 1. For interfering reflections between the image plane and the lens surface S107, the outermost chief ray intersects the image plane at a height of 37.3 mm, which corresponds to a height ratio of 64.3% with respect to the maximum filed height Y_{im}^{max}. For interfering reflections between the image plane and the

lens surface S112, the outermost chief ray intersects the image plane at a height of 107.7 mm, which corresponds to a height ratio of 185.7% with respect to the maximum field height Y_{im}^{max}, so that the doubly reflected chief ray strikes the image plane IM outside the image field.

[0046]

The lens surface S112, concave to the image plane IM, is critical for interfering reflections when no further lenses with refractive power follow the lens L15. In the case where the distance of the image plane IM from the vertex of the lens surface S112 is equal to half the radius of curvature of the lens surface S112, the light reflected back from the object to be illuminated into the image plane IM would be focused in the image plane IM when the image plane IM is illuminated nearly telecentrically, as in the present embodiment case. The concave lens surface S112 has, on the contrary, a radius of curvature of 100.7 mm and a distance from the image plane IM of 79.7 mm, so that the aperture plane of the concave lens surface S112, which functions as a mirror to calculate the interfering reflections, has a distance of 29.4 mm to the image plane IM. The ratio of this distance to half the radius of curvature is 0.6, so that a possible interfering reflection has only an insignificant effect.

[0047]

The concave lens surface S112 is disposed concentrically

with image plane IM as much as possible so that the central ray bundle enters the concave lens surface S112 at small angles of incidence and thus little aberration for field imaging is caused. The ratio of the distance from the vertex of the concave lens surface S112 to the image plane IM to the numerical value of the radius of curvature of the concave lens surface S112 is 0.79.

[0048]

Fig. 3 shows the lens section of a first embodiment of a REMA objective lens 309. Besides the lenses, the marginal rays RS of the middle ray bundle, and also the outermost chief ray HS and the rays bounding the ray bundle of the outermost chief ray HS, are shown in. The REMA objective lens 309 is constructed with rotational symmetry about the optical axis OA. The system data are set out in Table 3. As the lens material, calcium fluoride crystal (CaF_2) and quartz (S_iO_2) are used in this embodiment, and have refractive index of 1.5014, preferably 1.5603 at the working wavelength λ =193.3 nm. The elements of Fig. 3 corresponding to the elements of Fig. 1 are designated by the reference numerals, which are the reference numerals of Fig. 1 + 300. The description of Fig. 1 would be referred to for the description of the elements.

[0049]

The REMA objective lens 309 of Fig. 3 images an object filed with a magnification ratio β of -3.74 onto the image plane.

This lens consists of a first partial objective lens 311 and a third partial objective lens 301, and the construction is similar to that of the partial objective elements of Fig. 1. By the REMA objective lens 309, an image field with a diameter of 116.2 mm is illuminated. The image-side numerical aperture is 0.18. The photoconductivity of the REMA objective lens 309 is 20.9 mm. The entrance pupil of the REMA objective lens 309 is situated at infinity, so that the chief rays travel parallel to the optical axis OA in the object plane OBJ. The pupil imaging of the first partial objective lens 311 is corrected as well as possible. Nevertheless, because of the spherical aberration caused by the first partial objective lens 311 and the field curvature of the pupil imaging, the chief rays do not intersect the optical axis OA directly in the aperture plane APE, but intersect the optical axis dependently on the axial position to the diaphragm surface. In the REMA objective lens 309 of Fig. 3, the intersection points of the chief rays with the optical axis OA are situated in an axial region of 5.4 mm. This corresponds to 2.9% of an aperture diaphragm diameter, which is 188 mm.

[0050]

The pencils of rays starting from the object plane OBJ are respectively focused to a spot in the image plane IM. Within the image field, the maximum diameter of the spot images is 240 μm for all picture elements.

[0051]

The pupil function of the REMA objective lens 309 can be developed from the polynomial series according to Equation (1), and the coefficients of which can be read from Table 4.

[Table 2]

	coefficient	Polynomial part in the case of Y_{im}^{max} = 58.1 mm
C_1	-2.8278E-01mrad/mm	-16.43mrad
C_3	1.0607E-04mrad/mm^3	20.08mrad
C_5	6.5595E-09mrad/mm^5	4.34mrad
C_7	-7.525E-13mrad/mm^7	-1.68mrad
C_9	7.9719-17mrad/mm^9	0.60mrad

Table 4: Coefficient of Polynomial

[0052]

It can be seen from Table 4 that the greatest part to the spherical aberration of pupil imaging for the maximum positive field height Y_{im}^{max} is the third order part of +20.1 mrad. The total non-linear part is +24.1 mrad, so that the spherical aberration is clearly overcorrected. The ratio of non-linear part to linear part for the maximum field height Y_{im}^{max} is -1.46.

[0053]

The second partial objective lens 301 includes a first lens group 303 and a second lens group 305. The first lens group 303 includes lenses L35 and L36, the lens L35 being a meniscus with positive refractive power, the lens L36 being a meniscus with negative refractive power. The concave surfaces of the meniscuses respectively face toward the

aperture plane APE. The first lens group 303 has the aspheric lens surfaces S311 and S313.

[0054]

The second lens group 305 of the second partial objective lens 301 includes: a meniscus L37 with positive refractive power, having its concave lens surface facing toward the image plane IM; a meniscus L38 with positive refractive power, having its concave lens surface facing toward the aperture plane APE; and a meniscus L39 with negative refractive power, having its concave lens surface facing toward the aperture plane APE. The lens surface S320 is an aspheric lens surface, the surface description of which is given in Table 3. The radius of the envelope sphere, which intersects the aspheric lens surface S320 at the vertex and at the edge of the illuminated region at 81.1 mm, is 317.1 mm, so that the maximum vertical height deviation between the aspheric lens surface S320 and the envelope sphere is 0.87 mm.

[0055]

The lens L39 with negative refractive power has a lens surface S321 concave toward the image plane IM, the ratio of the radius of curvature to the lens diameter being 0.74. The lens L39 is the last lens having refractive power before the image plane IM, so that the concave lens surface S321 is arranged immediately before the image plane IM. The free working distance between the last lens L39 and the image plane

IM is 64.8 mm.

[0056]

Since the reticle is arranged in the image plane IM of the REMA objective lens 309, the lenses of the second lens group 305 of the second partial objective lens 301 have to be optimized to minimize the interfering reflections sometimes occurring between the partial reflecting reticle and the lens surface subject to residual reflections. The lens surfaces S316, S319, S320 and S321 are critical for interfering reflections, while for the lens surfaces S317 and S318, the outermost chief ray HS reflected at the reticle and at the lens surfaces no longer reaches the image plane but strikes the objective lens frame inside the REMA objective lens 309. For interfering reflections between the image plane IM and the lens surface S316, the doubly reflected chief ray HS intersects the image plane IM at a height of 41.9 mm, which corresponds to a height ratio of 72% with respect to the maximum field height Y_{im}^{max}. For interfering reflections between the image plane IM and the lens surface S319, the doubly reflected chief ray HS intersects the image plane IM at a height of 59.8 mm, which corresponds to a height ratio of 102.9% with respect to the maximum field height Y_{im}^{max}. For interfering reflections between the image plane IM and the lens surface S320, the doubly reflected chief ray HS intersects the image plane IM at a height of 83.3 mm, which corresponds to a height ratio of 143.4% with

respect to the maximum field height Y_{im}^{max}. For interfering reflections between the image plane IM and the lens surface S321, the doubly reflected chief ray HS intersects the image plane IM at a height of 158.8 mm, which corresponds to a height ratio of 273.3% with respect to the maximum field height Y_{im}^{max}.

[0057]

The concave lens surface S321 has a radius of curvature of 101.80 mm and a distance from the image plane IM of 91.62 mm, so that the aperture plane of the concave lens surface S321, which functions as a mirror to compute interfering reflections, has a distance of 40.7 mm from the image plane IM. The ratio of this distance to half the radius of curvature is 0.8, so that a possible interfering reflection has only an insignificant effect.

[0058]

The concave lens surface S321 is disposed concentrically with image plane IM as much as possible so that the central ray bundle enters the concave lens surface S321 at small angles of incidence and thus little aberration for imaging is caused. The ratio of the distance from the vertex of the concave lens surface S321 to the image plane IM to the numerical value of the radius of curvature of the concave lens surface S321 is 0.90.

[0059]

Due to the aberrations of field imaging of the REMS

objective lens 309, the energy-weighted average ray for an image point does not coincide with the corresponding chief ray. While in the object plane OBJ, the energy-weighted average ray and the chief ray coincide for each picture element and travel parallel to the optical axis OA, comatic aberration and oblique spherical aberration lead, for picture elements outside the optical axis OA, to a difference between the energy-weighted average ray and the chief ray. The direction of the energy-weighted average depends here on the extent of the pencils of rays in the aperture plane APE. When a ray bundle completely illuminates the aperture plane APE, a greater deviation of the energy-weighted average ray from the chief ray is to be expected, because of the greater comatic aberration, than for pencils of rays, which illuminate the aperture plane APE only in a region around the optical axis OA. The comatic aberration becomes extreme for an annular illumination of the aperture plane APE. The reason is that the ray pencils have only the outer aperture rays. The comatic aberration and oblique spherical aberration are corrected in the REMA objective lens 309 of Fig. 3 such that the deviation of the angles of the energy-weighted average rays from the chief ray angles, with complete illumination of the aperture plane, is smaller than ± 0.5 mrad for all field heights. The angular deviation is shown in Fig. 4 as a solid line for positive field heights.

[0060]

Fig. 5 shows a partial objective lens piece of a second embodiment of a REMA objective lens 509. Besides the lenses, there are drawn in the marginal rays RS of the central ray bundle and also the outermost chief ray HS and the rays bounding the ray pencil of the outermost chief ray HS. The REMA objective lens 509 is constructed with rotational symmetry about the optical axis OA. The system data are set out in Table 5. In the present embodiment, quartz (SiO_2) is used as the lens material, and has a refractive index of 1.5084 at the working wavelength λ of 248.3 nm. The elements of Fig. 5 corresponding to elements of Fig. 1 and Fig. 3 have the same reference numerals as in Fig. 1 or Fig. 3, increased respectively by the number 500, or 200. The description of Fig. 1 or Fig. 3 is referred to for a description of these elements.

[0061]

The REMA objective lens 509 of Fig. 5 images an object field with a magnification ratio $\beta = -3.50$ onto an image field. This includes a fist partial objective lens 511 and a third partial objective lens 501. An image field with a diameter of 113.3 mm is illuminated in the image plane IM by the REMA objective lens 509. The image-side numerical aperture is 0.19 The REMA objective lens 509 has the photoconductivity of 21.5 mm, which is greater still than the photoconductivity of the REMA objective lens 309 of Fig. 3. The entrance pupil of the

REMA objective lens 509 is situated at infinity, so that the chief rays travel parallel to the optical axis OA in the object plane OBJ. Due to the spherical aberration and field curvature of pupil imaging which are induced by the first partial objective lens 511, the chief rays intersect the optical axis OA with an axial displacement with respect to the aperture plane APE. For the REMA objective lens 509 of Fig. 5, the intersection points of the chief rays with the optical axis OA are 8.2 mm apart. This distance corresponds to 3.8% of the aperture diaphragm diameter, which is 217.2 mm.

[0062]

The pencils of rays emitted from the object plane OBJ are respectively focused to a spot image in the image plane IM. Within the image field, the maximum diameter of the spot images is 260 μm for all picture elements.

[0063]

The pupil function of the REMA objective lens 509 can be developed as a polynomial series according to equation (1), with the coefficients given in Table 6.

[Table 3]

	coefficient	Polynomial part in the case of Y_{im}^{max} = 56.6 mm
C_1	-5.341302E-01mrad/mm	-30.23mrad
C_3	2.526716E-04mrad/mm^3	48.81mrad
C_5	-8.320880E-09mrad/mm^5	-4.83mrad
C_7	2.120363E-12mrad/mm^7	3.95mrad
C_9	-6.339048E-17mrad/mm^9	-0.38mrad

Table 6: Coefficient of Polynomial

[0064]

It can be seen from Table 6 that the greatest part to the spherical aberration in pupil imaging for the maximum positive field height Y_{im}^{max} is the third order part of +45.8 mrad. The total non-linear part is +44.5 mrad, so that the spherical aberration is clearly overcorrected as compared to the first embodiment where the REMA objective lens is used. The ratio of non-linear part to linear part for the maximum field height Y_{im}^{max} is −1.47.

[0065]

The second partial objective lens 501 of the REMA objective lens is constructed by a first lens group 503 and a second lens group 505. The first lens group 503 includes a lens L56 and a lens L57, the lens L56 being a meniscus with positive refractive power, the lens L57 being a meniscus with negative refractive power. The concave surfaces of the meniscuses respectively face toward the aperture plane APE. The lens L56 has an aspheric lens surface S513.

[0066]

The second lens group 505 of the second partial objective lens 501 is constructed by a meniscus L58 with positive refractive power, having its convex lens surface facing toward the aperture plane APE, a meniscus L59 with positive refractive power, having its convex lens surface facing toward the image plane IM, a biconvex lens 510 with positive refractive power,

and a meniscus L511 with negative refractive power, having its convex surface facing toward the aperture plane APE. The lens surface S523 is an aspheric lens surface, the surface description of which is given in Table 5. The radius of the envelope sphere, which intersects the aspheric lens surface S523 at the vertex and at the edge of the illuminated region of the aspheric lens surface S523 at 99.6 mm, is -238.6 mm, so that the maximum vertical height deviation between the aspheric lens surface S523 and the enveloper sphere is -1.61 mm. The second lens group 505 contains a further aspheric lens surface S518, in order to be able to provide the large overcorrection of the spherical aberration of pupil imaging. The radius of the envelope sphere, which intersects the aspheric lens surface S518 at the vertex and at the edge of the illuminated region of the aspheric lens surface at 109.9 mm, is 170.1 mm, so that the maximum vertical height deviation between the aspheric lens surface S518 and the envelope sphere is 1.66 mm.

[0067]

The lens L511 has a lens surface S525 concave toward the image plane IM, the ratio of the radius of curvature to the lens diameter being 0.70. The lens L511 with negative refractive power is the last lens having refractive power before the image plane IM, so that the concave lens surface S525 is arranged immediately before the image plane IM. The

free working distance between the last lens and the image plane IM is 67.9 mm.

[0068]

The lenses of the second lens group 505 of the second partial objective lens 501 have to be optimized to minimize the interfering reflections. The lens surface S519, S522, S524 and S525 are critical for interfering reflections in the REMA objective lens 509 of Fig. 5, while for the lens surfaces S518, S520, S521 and S523, the outermost chief ray HS reflected at the reticle and the lens surfaces no longer reaches the image plane. For interfering reflections between the image plane IM and the lens surface S519, the outermost chief ray HS intersects the image plane IM at a height of 40.1 mm, which corresponds to a height ratio of 70.9% with respect to the maximum field height Y_{im}^{max} of 56.6 mm. For interfering reflections between the image plane IM and the lens surface S522, the outermost chief ray HS intersects the image plane IM at a height of 58.6 mm, which corresponds to a height ratio of 103.5% with respect to the maximum field height Y_{im}^{max}. For interfering reflections between the image plane IM and the lens surface S524, the outermost chief ray HS intersects the image plane IM at a height of 52.4 mm, which corresponds to a height ratio of 92.6% with respect to the maximum field height Y_{im}^{max}. For interfering reflections between the image plane IM and the lens surface S525, the outermost chief ray HS intersects the

image plane IM at a height of 180.7 mm, which corresponds to a height ratio of 319.3% with respect to the maximum field height Y_{im}^{max}.

[0069]

The concave lens surface S525 has a radius of curvature of 96.08 mm and a distance from the image plane IM of 96.71 mm, so that the aperture plane of the concave lens surface S525, which functions as a mirror to compute interfering reflections, has a distance of 48.7 mm from the image plane IM. The ratio of this distance to half the radius of curvature is 1.0, so that a possible interfering reflection has only an insignificant effect.

[0070]

The concave lens surface S521 is arranged concentrically with the image plane IM as much as possible so that the central ray bundle enters the concave lens surface S521 at small angles of incidence and thus little aberration for imaging is induced. The ratio of the distance of the image plane IM from the vertex of the concave lens surface S521 to the numerical value of the radius of curvature of the concave lens surface S521 is 1.01.

[0071]

The angular deviation between the energy-weighted average rays and the chief rays for the REMA objective lens 509 of Fig. 5 is shown as the solid line in Fig. 6 for positive field heights. It is smaller than +0.5 mrad for all field

heights.

[0072]

Fig. 7 is a schematic diagram of a first embodiment of a microlithographic projection exposure apparatus 715, which has two light sources 717 and 717′ in this case. As the light source 717, especially DUV laser or VUV laser can be used, such as an ArF laser for 193 nm, a F_2 laser for 157 nm, an Ar_2 laser for 126 nm and a NeF laser for 109nm. A parallel light bundle is generated by a beam generating optical system 719, and enters an optical element 721 for increasing the divergence. As the divergence increasing optical element 721, a diffractive or refractive lattice element, for example, may be used. Each lattice element generates a ray bundle, the angular distribution of which is determined by the expansion ratio and focal length of the lattice element. The lattice plate is located in or near to the object plane of a following objective lens 723. The pencils of rays generated from the lattice elements are superposed in the aperture plane 725 of the objective lens 723. The objective lens 723 can be designed as a zoom objective lens, in order to vary the extension ratio of the illumination of the aperture plane 725. An annular illumination with variable ring width can also be achieved by the use of two axicon lenses, which are movable along the optical axis and disposed immediately before the aperture plane 725. This type of zoom axicon objective lens is known from

DE 44 41 947 A. The illumination can be also varied by exchanging an aperture-forming element 721. Special aperture-forming elements 721 also permit the so-called quadrupole illumination with four separate regions. The aperture plane 725 of the objective lens 723 is the entry plane of a comb-shaped condenser 727. The aperture plane APE of the whole illuminating system is situated in the vicinity of the exit plane of the comb-shaped condenser 727. The illumination can additionally be controlled in the aperture plane APE by means of a mask 729 or transmission filter. The partial objective lens 701 of Fig. 1 follows the comb-shaped condenser 727. The elements in Fig. 7 corresponding to elements of Fig. 1 have the same reference numerals as in Fig. 1, increased by the number 700. Reference is made to the description of Fig. 1 for a description of these elements. A cubic polarization beam splitter is situated between the first lens group 703 and the second lens group 705 of the partial objective lens 701, and superposes the beam paths starting from the light sources 717 and 717'. Thus, all the components of the illuminating device up to the cubic beam splitter 731 are present twice over. The components of the second optical system branch 737 up to the cubic beam splitter 731 have dashed reference numerals in comparison with the first optical system branch 735. In order to achieve the superposition to take plate free from loss as much as possible, the light which is to be transmitted at the

beam splitter surface 733 must be polarized in the plane of incidence, while the light which is to be reflected at the beam splitter surface 733 must be polarized perpendicularly to the plane of incidence. This can be achieved in that polarization rotating means or polarization select means such as polarization filters or $\lambda/4$ plates, are disposed in the aperture plane APE. When the light source 717 already produces linearly polarized light, the state of polarization can be suitably set by alignment of the light source 717. A reticle 739 imaged on a wafer 743 by a projection objective lens 741 is situated in the image plane IM of the partial objective lens. The reticle 739 and the wafer 743 a both disposed on a holder (not shown). The reticle 739 and the wafer 743 may be exchanged by the holder. In the so-called scanner system, the reticle 739 and the wafer 743 are moved in the scanning direction in proportion to the imaging magnification ratio of the projection objective lens 741.

[0073]

The projection objective lens of Fig. 2 of DE 199 42 281.8, which has an imaging magnification ratio of -0.25, can be used as the projection objective lens shown only schematically in Fig. 7. The system data on the projection objective lens are given in Table 1 of DE 199 42 281. 8, the distance between the object plane and the vertex of the lens L101 being 49.2885 mm. The pupil function of the partial objective lens 701 of Fig.

1, the system data of which are given in Table 1 of the present application, is exactly matched to the angular distribution of the object - chief ray of the projection objective lens 741. Fig. 8 shows the deviation of the pupil function of the partial objective lens 701 from the object - chief ray angle as a solid line 845. The maximum deviation is ± 0.4 mrad. By the matching of the partial objective lens 701 to the projection objective 741, it is possible to permit a considerable undercorrection of the spherical aberration of the pupil aberration in the projection objective lens 741.

[0074]

Fig. 9 is a schematic diagram of a second embodiment of a microlithographic projection exposure apparatus 915. The elements of Fig. 9 corresponding to the elements of Fig. 7 have the same reference numerals as in Fig. 7, increased by the number 200. Reference is made to description of Fig. 7 for a description of these elements. In the second embodiment, however, a glass rod 951 is used for homogenizing the distribution of light. The microlithographic projection exposure apparatus 915 has, instead of the comb-shaped condenser and the partial objective lens, a further divergence-increasing optical element 947, a coupling-in objective lens 949, the glass rod 951, a masking device 953, and a REMA-objective lens 909 for imaging the masking device 953 on the reticle 939. This type of illumination system is

described in DE 195 20 563 A1 (U.S. Application No. 09/315267). In this case, the REMA objective lens 909 is identical to the REMA objective lens 309 of Fig. 5, the system data of which are given in Table 3.

[0075]

The glass rod 951 generates a virtual secondary light source depending on the number of times of reflection in the glass rod 951 in a plane of incidence 955of the glass rod 951. This is imaged by the first partial objective lens 911 of the REMA-objective lens 909. In this case, the image of the virtual secondary light source is not in the aperture plane APE, but defocused in the direction of the image plane IM. While the first partial objective lens 911 images the entrance pupil in an infinite distance on the aperture plane APE, the virtual secondary light source apart by the length of the glass rod is imaged between the lens L35 and the lens L36. Advantageously the REMA objective lens 909 is designed so that in order to prevent damage of material, the image of the virtual second light source and a plane causing strong luminance fluctuation in relation thereto are not superposed on the lens. This is achieved by disposing the lens L35 in the vicinity of the aperture plane APE and on the other hand, taking an enough large void between the lens L35 and the lens L36. As another possibility, it may be considered to use material having resistance to the beam such as quarts fluoride as the lens

material in the position of the image of the virtual secondary light source.

[0076]

A rectangular field, whose luminance fluctuation is under 2%, in the object plane of the REMA objective lens 909, is illuminated by the glass rod 951. The REMA objective lens 909 images this homogeneously illuminated filed onto the reticle. The distribution of illumination on the reticle is nearly independent of the illumination of the aperture plane APE, which was previously adjusted with a zoom axicon objective lens, for example. The luminance fluctuations, which are caused by the variable aperture illumination, are advantageously under ± 1%. In the case of the REMA objective lens 909, the luminance fluctuations are only ± 0.2%. This is achieved by correcting the distortion of the image dependent on the aperture.

[0077]

The projection objective lens of Fig. 8 of DE 199 42 281.8 which has an imaging magnification ratio of -0.25, can be used for the projection objective lens shown only schematically in Fig. 9. The system data are given in Table 4 of this patent specification, the distance between the object plane and the vertex of the lens L401 being 33.4557 mm. The pupil function of the REMA objective 909 is exactly matched to the angular distribution of the objective lens - chief ray of the projection

objective lens 934. Fig. 10 shows the deviation of the pupil function of the partial objective lens and the angular distribution of the objective lens - chief ray as a solid line 1045. The maximum deviation is 0.34 mrad.

[0078]

A possibility is shown by the embodiments of providing illuminating systems, which permit an undercorrection of the spherical aberration of pupil imaging in a following projection objective lens. Thus, correction means within the projection objective lens can be saved.

[Table 4]

Lens	Surface	Radius [mm]	Thickness [mm]	Material	Diameter [mm]
	APE	0.00	1.59		187.9
L11	S102	260.32	39.87	SiO2	195.5
	S103	567.25	135.51		191.1
L12	S104	234.09	15.00	SiO2	184.3
	S105	180.39	259.04		178.1
	S106	0.00	206.08		213.7
L13	S107	1539.49	38.23	SiO2	245.5
	S108	-306.69	52.29		245.8
L14	S109	130.37	52.39	SiO2	190.4
	S110	844.68	15.14		175.2
L15	S111	555.42	5.86	SiO2	160.8
	S112	100.69	79.74		134.3
	IM	0.00	0.00		116.0

$$z = \frac{\frac{1}{R}h^2}{1+\sqrt{1-(1-EX)\left(\frac{1}{R}\right)^2 h^2}} + \sum_{k=1} c_k h^{2k+2}$$

z: vertical height, h: height, R: radius, EX: eccentricity

C_K: aspheric constant

plane	EX	C1	C2	C3	C4
S102	-0.6130	-9.1133E-09	1.09311E-12	-1.1185E-16	4.3105E-21
S104	3.5118	2.6731E-08	-1.1221E-12	7.9601E-16	-4.1294E-21
S111	2.0197E+12	-5.5586E-08	4.3580E-12	-1.9413E-16	2.3919E-21

Table 1: optical data of partial objective lens of Fig. 1

[Table 5]

	plane	radius [mm]	thickness [mm]	material	diameter [mm]
	OBI	0.00	32.95		31.2
L31	S302	-38.69	37.88	CaF2	61.9
	S303	-73.41	0.90		114.4
L32	S304	2696.07	33.32	CaF2	168.2
	S305	-191.13	0.90		178.0
L34	S306	329.78	41.98	SiO2	216.0
	S307	-514.77	28.53		219.1
L35	S308	334.07	34.03	SiO2	227.6
	S309	-570.33	161.49		227.6
	APE	0.00	6.00		188.0
L36	S311	130.20	30.35	SiO2	195.8
	S312	324.12	99.95		192.5
L37	S313	211.39	11.40	SiO2	168.8
	S314	127.10	230.32		158.8
	S315	0.00	216.90		197.4
L38	S316	-851.36	37.33	SiO2	237.1
	S317	-237.99	0.90		240.0
L39	S318	133.05	46.59	SiO2	212.7
	S319	275.70	42.03		200.4
L310	S320	240.69	12.00	SiO2	162.1
	S321	101.80	91.62		138.5
	IM	0.00	0.00		116.2

$$x = \frac{\frac{1}{R}h^2}{1+\sqrt{1-(1-EX)\left(\frac{1}{R}\right)^2 h^2}} + \sum_{k=1} c_k h^{2k+2}$$

z: vertical height, h: height, R: radius, EX: eccentricity,

C_K: aspheric constant

plane	EX	C1	C2	C3	C4
S308	-2.4978	-4.3481E-08	-7.8594E-14	-2.0935E-17	8.6082E-23
S311	0.2840	-4.1616E-08	-1.1523E-12	-4.8136E-18	-5.8384E-21
S313	0.6222	-3.5043E-08	1.0875E-12	2.1557E-16	-3.6907E-21
S320	0.9715	-5.9896E-08	-2.8284E-12	1.2407E-16	2.9936E-21

Table 3: optical data of partial objective lens of Fig. 3

[Table 6]

lens	plane	radius [mm]	thickness [mm]	material	diameter [mm]
	OBJ	0.00	44.12		32.4
L51	S502	-42.28	30.35	SiO2	73.0
	S503	-78.14	0.90		121.7
L52	S504	-338.66	37.30	SiO2	163.1
	S505	-124.59	0.86		177.2
L53	S506	2979.91	45.50	SiO2	221.0
	S507	-219.18	1.65		228.3
L54	S508	5302.65	40.00	SiO2	241.5
	S509	-230.16	156.30		244.0
L55	S510	-377.28	26.00	SiO2	241.3
	S511	-224.20	40.60		243.4
	APE	0.00	6.00		217.2
L56	S513	212.83	39.70	SiO2	216.9
	S514	1296.09	120.30		211.7
L57	S515	523.30	11.70	SiO2	166.8
	S516	128.28	148.73		155.8
	S517	0.00	113.55		233.3
L58	S518	146.29	33.90	SiO2	219.7
	S519	345.28	94.30		216.2
L59	S520	-268.89	55.00	SiO2	208.1
L59	S521	-200.89	0.80		216.3
L510	S522	1616.33	35.50	SiO2	202.3
	S523	-174.93	2.20		199.1
L511	S524	256.46	15.90	SiO2	163.9
	S525	96.08	96.71		137.4
	IM	0.00	0.00		113.3

$$x = \frac{\frac{1}{R}h^2}{1+\sqrt{1-(1-EX)\left(\frac{1}{R}\right)^2 h^2}} + \sum_{k=1} c_k h^{2k+2}$$

z: vertical height, h: height, R: radius, EX: eccentricity,

C_K: aspheric constant

plane	EX	C1	C2	C3	C4	C5
S509	-1.1741	3.9084E-08	3.8630E-13	6.55864E-17	-3.3899E-21	1.2432E-25
S513	-0.2501	-2.1870E-08	5.4913E-14	-7.7358E-17	4.1956E-21	-1.2014E-25
S518	0.2356	-3.4023E-08	-1.0405E-12	7.3414E-17	-9.7841E-21	3.0608E-25
S523	-0.8321	1.4350E-07	-4.9565E-12	5.7530E-16	-3.6123E-20	1.5494E-24

Table 5: optical data of partial objective lens of Fig. 5

[Brief Description of the Drawing]

Fig. 1 is a diagram showing a lens section piece of a partial objective lens according to the invention;

Fig. 2 is a graph of pupil function of the partial objective lens of Fig. 1;

Fig. 3 is a diagram showing a lens section piece in a first embodiment of REMA objective lens;

Fig. 4 is a graph showing the deviation between the angular distribution of weighted beam over a field height and the pupil function of the REMA objective lens of Fig. 3;

Fig. 5 is a diagram showing a lens section piece in a second embodiment of the REMA objective lens;

Fig. 6 is a graph showing the deviation between the angular distribution of weighted beam over a field height and the pupil function of the REMA objective lens of Fig. 6;

Fig. 7 is a schematic diagram of a micrographic projection exposure apparatus having the partial objective lens of the invention;

Fig. 8 is a graph showing the deviation between the pupil

function of the objective lens on the object side of the projection objective lens in Fig. 2 and the pupil function of the REMA objective lens of Fig. 3 according to DE 19942291.8;

Fig. 9 is a schematic diagram of a micrographic projection exposure apparatus having the REMA objective lens of the invention; and

Fig. 10 is a graph showing the deviation between the pupil function of the objective lens of the object side of the projection objective lens in Fig. 8 and the pupil function of the REMA objective lens of Fig. 6 according to DE 19942291.8.

[Description of the Reference Numerals and Signs]

1: partial objective lens 3: lens group 5: lens group L11: lens L12: lens L13: biconvex lens L14: meniscus L15: lens S102: aspherical lens surface S104: aspherical lens surface S107: lens surface S108: lens surface S109: lens surface S110: lens surface S111: lens surface S112: lens surface S111: aspherical lens surface S112: concave lens surface APE: aperture plane OA: optical axis IM: aperture plane HS: chief ray RS: marginal beam IM: MA plane OBJ: object plane